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Does it make a difference to the public where CO_2 comes from and where it is stored?

An experimental approach to enhance understanding of CCS perceptions

Elisabeth Duetschke[a]*, Diana Schumann[b], Katja Pietzner[c], Katharina Wohlfarth[a], Samuel Höller[c]

[a]*Fraunhofer Institute for Systems and Innovation Research, Germany*
[b]*Forschungszentrum Juelich GmbH, Germany*
[c]*Wuppertal Institute for Climate, Environment and Energy, Germany*

Abstract

Among the factors that decelerate progress of CCS demonstration and deployment is the lack of public acceptance of local projects in Germany as well as in other countries. The study presented here aims to take the issue of public CCS perceptions further by empirically investigating the relevance of different specifications of the three main steps of the CCS chain, i.e. capture, transport and storage. An experimental approach is chosen and applied in an online survey with a representative sample from Germany with 1830 participants. With regard to possible CO_2 sources we varied whether the CO_2 of a specific setting is captured i) as part of an energy-intensive industry process (e.g. production of steel or cement), ii) from a power plant running on biomass, or iii) a coal-fired power plant. For transport, half of the settings described made reference to transport of CO_2 via pipelines, the other half did not provide information about transport. With regard to storage the setting descriptions i) either explained that CO_2 can be stored in saline aquifers, ii) can be used to enhance gas production from an emptying natural gas field or iii) can be stored in a depleted natural gas field. We find that overall the average of the ratings for perception of the settings fall into the neutral part of the answering scale. If the source of CO_2 is a coal-fired power plant the setting is perceived less positively than if it includes biomass or industry. A significant interaction effect between transport and storage specifications is observed. This points out that storage in saline aquifers is perceived more negatively than a combination with enhanced gas recovery while storage in a

* Corresponding author. Tel.: +49-721-6809159; fax: +49-721-680977159.
E-mail address: elisabeth.duetschke@isi.fraunhofer.de

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depleted natural gas field is rated less positively if a pipeline is mentioned and more positively if no transport option is mentioned.

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Keywords: Public perception; acceptance; different CCS-options; survey; experimental study

1. Introduction and background

Carbon Capture and Storage (CCS) has been discussed as a technology that is supposed to significantly contribute to the mitigation of climate change [e.g. 1, 2]. However, the pace of development and uptake of CCS is slow globally and has even stopped in some countries like Germany. Among several reasons [cp. 3] this is also due to the fact that CCS projects have met low levels of acceptance in quite a number of countries [4, 5, 6, 7] and projects were either directly stopped by local public opposition or indirectly by lack of political support [8] [9]. Thus, the public's perception and evaluation of CCS will be important for the future of the technology.

So far, CO_2 capture, transport and storage technology projects as well as research on CCS acceptance have mainly focused on investigating or demonstrating the capture of CO_2 from fossil energy sources [e.g. 10, 11, 12] with energy production from coal being predominant. [1] Fossil fuels and among them especially coal are energy sources which are disapproved by a majority of the public [13, 14]. Furthermore, Viebahn et al. [15] point out, that it might not be necessary to develop CCS e.g. for the German power plant sector but that more important potentials may lie in industry and – if other measures for climate change mitigation fail – in biomass with CCS. However, societal acceptance issues are also relevant for such an implementation of CCS.

Studies on public perception and acceptance of CCS have pointed out that the issues around CO_2 storage are more likely to evoke opposition by the public than capture and transport [8, 16, 17]. However, there is very little research that systematically explores perceptions and evaluations of the three main steps of the CCS chain in different settings, i.e. varying CO_2 sources and storage options.

Wallquist et al. [8] contribute to fill this gap by applying a stated choice design to explore preferences of a non-representative sample of 139 Swiss citizens for twelve different CCS-settings. These settings included an energy generation facility either based on natural gas or biogas. With regard to transport, the settings included one of three options: either a CO_2-pipeline or a natural gas-pipeline that passes near the respondents' house or no pipeline passing nearby. Furthermore, the storage location was indicated to be either in the respondents' municipality or in a neighboring canton. Thus, besides technological variations, the settings also differed in the degree of proximity of the installations. They found that settings including biogas-fuelled power plants are preferred to gas-fired ones and that effects of proximity are diminished in this case. The pipeline-factor turned out to be the most relevant with a clear preference for no pipeline nearby. For storage, participants preferred a storage location farther off in the neighboring canton.

An earlier study by de Best-Waldhober & Daamen [18] compared the public perceptions and preferences for different CCS-technologies, mostly focusing on the CO_2-source. The technologies included the evaluation of a large modern coal fired power station with CCS, the conversion of natural gas into electricity with CCS, large coal-fired hydrogen stations with CCS, conversion of natural gas into hydrogen with CCS, retrieval of methane gas by storing CO_2 in coal beds[2] and a small scale conversion of natural gas into hydrogen with CCS. Preferences were elicited from nearly 1000 individuals from the Netherlands using an Information Choice Questionnaire, i.e. an instrument that is an established methodology to measure evaluations also towards fairly unknown technologies as it also

[1] Cp. for example the six projects included under the European Energy Programme for Recovery (EEPR) [36] which all aimed at implementing CCS at coal-fired power plants (one of them co-firing biomass) (EEPR factsheet Carbon Capture and Storage summary, 2013).

[2] This option thus combines CO_2-source and storage.

provides the participant with information. Results showed that gas options were seen more positively than coal options with effect sizes, however, being relatively small.

To the best of our knowledge, no study on the public perception of CCS has so far been published which has systematically analyzed the influence of different designs of the three main steps of the CCS chain, i.e. variation of the CO_2-source from which the CO_2 is captured, transport and storage. Against this background, the study presented here aims to take this issue further by empirically investigating the relevance of different specifications of the three main steps of CCS on the public perception of CCS as well as possible interactional effects between the specifications.

The subject matter of this paper is structured as follows: The next section describes the chosen CCS parameters that will be included in the empirical study, thereby justifying why they were chosen and summarizes research on CCS perceptions on the parameters. This is followed by a description of the methods applied for the empirical study; afterwards results will be presented and finally discussed.

2. CCS Parameters

This section shortly describes the CCS parameters which will be subject of the empirical analysis (see Table 1 for an overview) and outlines why they were chosen. Furthermore, it briefly reviews research on public perception of the parameters.

2.1. Capture: CO_2-source

The first part of the CCS chain is the capture of CO_2 from a CO_2 emitting source. The technology has been applied in some cases for oil and gas refinery, but as pointed out above, CCS is most often discussed as a technical option for reducing CO_2 emissions from *coal-fired power plants*. It enables to capture, transport and store a significant amount (a maximum of 90%) of the emitted CO_2. But the efficiency of the entire power plant is reduced significantly by up to one third due to additional energy needs for the capture process. Integrating carbon capture into the production circle of a coal-fired power plant is the standard case which has been studied most often world-wide and is therefore included in the empirical analysis.

The integration of co-firing with biomass or pure *biomass power plants* for power and heat production would have a positive impact on emissions because “negative” CO_2 emissions can be achieved. Plants and trees absorb CO_2 during growth to build up biomass. Burning this biomass would release the CO_2 back into the atmosphere. If the CO_2 is separated from the flue gas and injected into storage formations, it could not only be avoided, but extracted long-term from the atmosphere. In the light of ambitious climate mitigation targets, these negative emissions could become relevant if it proves to be impossible to achieve the set reduction targets in other areas [19, 15]. Furthermore, the results from Wallquist et al. [9] point out that biomass with CCS might be perceived more favourably by the public than other capture options. Hence, biomass is the second possible CO_2-source, which is part of the analysis.

For the power sector, climate friendly solutions to substitute power plants based on fossil fuels exist with renewable energies beyond the use of sustainable biomass. A different picture has to be drawn for industrial emission sources in *energy-intensive industries* like iron and steel plants, the glass industry, cement production, and the chemical industry. In the industrial context there are virtually no alternative options available on the same scale that could assist in a further reduction of CO_2 emissions [15]. In many processes, CO_2 is emitted in a higher concentrated state than from power stations (3 to 25 percent), and could therefore be separated more easily from flue gases. Thus, industry may become the main case for CCS in the future in highly industrialised countries like Germany and therefore CO_2 captured from industrial production comprised the third source for the empirical study. In our study we analyse in how far coal, biomass or industry as a possible source for CO_2 elicit different perceptions of CCS.

As already mentioned in the introductory section, coal as a fossil energy source is perceived less positively by the public than renewable energy sources like hydropower, wind and solar. Biomass usually ranges behind the latter, but above coal and nuclear [cp. 11, in 14, 13]. Thus, a CCS-setting that includes biomass may be perceived more positively than one based on coal. This expectation is backed up by the findings by Wallquist et al [9] where biomass settings were rated more positively than gas settings which is also a fossil fuel like coal.

Several studies point out, that CCS acceptance is strongly influenced by perceived societal benefits of the technology [20, 21, 22]. Possibly individuals are more convinced of the benefits of industry to contribute to national welfare than of coal-fired power plants which are perceived to be replaceable by renewable energies. Thus, energy-intensive industry as a source of CO_2 for capture might also be perceived more positively than a coal-fired power plant.

2.2. Transport

To conduct successful CCS projects, the captured CO_2 has to be transferred from the emission source to potential sinks. Transport is also possible both onshore and offshore through *pipelines*; and onshore by truck or train and offshore by ship. The CO_2 is compressed to a liquid to be transported. Pipelines are most suitable for large-scale CO_2 transportation [23], therefore CO_2 transport by truck, train or ship is more unusual, particularly in the future. Pipeline transport is well established for natural gas, oil, condensate and water, but there is also some experience of CO_2 pipeline transport, mainly in the US [24]. In order to limit the number of variations in our empirical study we focus on pipelines.

Only a few studies on CCS acceptance have investigated the transport step. With regard to pipelines, Wallquist et al. [9] found that the nearby existence of pipelines was the factor that most strongly influenced the evaluation of a CCS setting in their study and that no pipeline was preferred. Work by Gough et al. [24] as well as Schumann [20] confirms that CO_2 pipelines are seen critically by the public and associated with possible risks. Thus, we would expect that settings mentioning a pipeline will be perceived more negatively than settings not mentioning a pipeline.

2.3. Storage

With regard to storage we look at three possibilities out of the different geological formations that are discussed for CO_2 storage. This is the most crucial step with regard to the public acceptance of the CCS chain. We chose those three that are most likely for a central European country like Germany. This means that of the formations discussed, we do not look at possibilities which are related to oil occurrences.

The injection of CO_2 into *deep saline aquifers* is generally considered to be the most important option for storing CO_2, because these formations are expected to offer the greatest storage potential for Germany [25]. Aquifers are deposits of rock saturated with drinking water or brine in their porous sedimentary strata whereas only the latter are considered for the storage of CO_2.

Other possibilities are *depleted natural gas fields*. Carbon dioxide is injected into the depleted field. Due to the difference in density to the water in the formation (similar to the formation of oil and natural gas), the CO_2 rises and collects beneath the roof consisting of an impermeable sealing layer or cap, which kept the natural gas in the formation.

The initiation of the commercial application of CCS could be triggered by the expansion of *enhanced gas recovery* (EGR). Here, naturally occurring CO_2 or – in case of a combination with CCS – CO_2 captured from a CO_2 source is injected into natural gas fields to enhance extraction. Using this method, some of the gas is forced out of the formation. However, EGR technology is still a long way from becoming commercially available [26]. We therefore look at three storage options: saline aquifers, depleted natural gas fields, and enhanced gas recovery.

No earlier research could be found that specifically compares the acceptance or public preferences of certain geological formations for CO_2 storage. However, from the range of fossil fuels, natural gas is the one usually evaluated most positively [14, 13]. Thus, it can be argued that storage options referring to depleted natural gas fields. Furthermore, while natural gas and gas extraction are probably topics the public is more likely to be familiar with than with saline aquifers. Against this background it is possible that the two gas options are seen more positive than storage in saline aquifers. Moreover, we assume that EGR will be perceived even more positive than storage in a depleted gas field. The argument behind this way of thinking is that in this case the CO_2 storage is related to additional benefits as the injection supports the extraction of natural gas. This argument fits with research that shows the positive influence of perceived benefits on acceptance [21, 20, 14].

3. Methods

We applied an experimental design for the online survey of this study. The experimental approach was chosen in line with earlier studies on CCS acceptance (cp. Terwel et al. [27], for work on trust in stakeholders; Ter Mors et al. [28] 2010, or Daamen et al. [29], for studies on communication effectiveness). This is advantageous as detailed knowledge of the CCS technology and experiences with CCS projects is low amongst the public [6]. Experimental designs allow combining the provision of information with the measurement of attitudes. The information presented can be varied systematically in an experimental approach, and thus it is possible to measure the influence of specific information on spontaneous attitudes [18].

3.1. Experimental approach

For the purpose of our study we developed short explanations of the possible CCS settings to the participants (cf. Annex). The information provided varied systematically between the settings of the three factors: the CO_2 source from which CO_2 is captured, transport and the CO_2 storage formation (see Table 1 for an overview).

Table 1. Parameters of the CCS settings under study.

CO_2 sources	Transport options	Storage options
Industry	via Pipeline	Saline aquifer
Biomass power plant	not mentioned	Enhanced gas recovery
Coal-fired power plant		Depleted gas field

Taking together, the parameters (3*2*3) that were varied resulted in 18 different possible CO_2 settings. Only one of the 18 CCS settings was presented to each survey participant in order to avoid influences of the settings presented earlier on the evaluations.[3] This was followed by a list of eleven pairs of adjectives (so called semantic differential) described in more detail below. In order to carry out statistical tests also for possible interaction effects between the single options within the steps, each of the settings was rated by at least 100 respondents, thus the overall sample size encompassed up to over 1800 individuals.

3.2. Procedure

The overall questionnaire was divided into different blocks of topics: After a short introduction at the beginning, participants were asked several questions about their beliefs on climate change, their opinion on the use of different energy sources, their knowledge of CCS and their attitude towards technology and nature. Then one of the 18 different settings was randomly presented to be rated by the participant. The rating consisted of eleven different Likert scales, mostly pairs of adjectives, addressing positive or negative aspects regarding the CCS setting: innovativeness, effects on environment or climate, safety, technical feasibility and personal concern (see Table 3 and Annex for more details). Additionally, the participants were asked further questions, e.g. about their opinion of using CCS respective to the source of CO_2 given in the presented setting and their attitude towards the relevance of industry, biomass power plants and coal-fired power plants for Germany in general. The last block addressed sociodemographic variables, containing items on age, gender, household size, education, income, home ownership and Bundesland (= federal state) (see Table 2). In this paper we focus on analyzing the ratings of several settings which differ regarding to source, transport and storage-option of CO_2.

[3] That order effects are relevant in this context is shown in a study by de Best-Waldhober et al. (2012) where e.g. CCS options for energy generation were rated more positively when they were the first in a row of energy generation settings.

3.3. Sampling and description of the sample

With the support of a market research institute, 1830 participants representative in relation to the German population with regard to gender, age, education and German federal state, were recruited to complete the experimental online-survey in November and December 2013. Table 2 provides an overview of socio-demographic characteristics of the participants. Microcensus[4] was used as data for comparison and confirmed representativeness. The 18 sub-groups of participants which rated each setting do not differ significantly on any of the sociodemographic variables (tested with ANOVAs for age respectively Chi^2-Tests for gender, education, income, number of persons in household and home ownership).

Table 2. Sample description.

Variable		Sample (N=1830)	Population (based on Microcensus)
Age	18-29 years	20,2%	17,0%
	30-39 years	16,2%	14,0%
	40-49 years	21,1%	21,0%
	50-59 years	17,4%	17,0%
	60 years and older	25,1%	31,0%
Gender	Male	49.3%	48,8%
	Female	50.7%	51,2%
Household size	Mean	2.3 persons	2,01 persons
Education	No completed vocational training	23.6 %	24,0%
	Completed apprenticeship	55.1 %	56,0%
	Technician/ Master	9.4 %	10,0%
	University degree (diploma/ master/ bachelor)	11.9 %	10,0%
Home ownership	I live in a rented flat	58.3 %	
	I live in a rented house	5.4 %	
	I live in my own flat	6.7 %	
	I live in my own house	28.5 %	
	Other	1.1 %	
Net income per household/ month	Less than 1000 €	18.7 %	
	1000-2999 €	50.4 %	
	3000-4999 €	13.3 %	
	5000-7000 €	3.4 %	
	More than 7000 €	0.3 %	

3.4. Preparation of dataset

Additionally to the 7-point Likert-scales used for rating attitudes and opinions, participants had the possibility to choose the "don't know/ not specified"-category. Answers of those categories were treated as missing values. For respondents where more than 30% of those answers were coded as "missing", the participant was excluded from the analysis due to the assumption that no valid answers were provided by this respondent. Therefore our sample was reduced to 1672 participants. In order to use the ratings of CCS settings as an independent variable in the following analyses, the suitability of aggregating the ratings of the single items into a scale was examined by using a factor analysis and a test of reliability. We used the principal component factor method for factor extraction[5] and extracted one component and all eleven items collapsed into one factor. Table 3 shows the respective items and factor with loadings (i.e. the correlation between the (latent) scale and the items). We calculated Cronbach's α for this scale of eleven items as .94, which indicates high reliability as sufficient reliability is usually assumed for values above .7 [31]. Thus, in the following analysis, we use the mean of those items as the new variable "setting rating".

[4] The microcensus is a sample survey which is conducted each year and covers about 1% of the German population.

[5] Bartlett's test on sphericity $Chi^2(55)=10056.368$; $p<.001$; Kaiser-Meyer-Olkin measure=.934, which indicates our method as suitable values above > .5 are regarded as suitable (Cureton [30])).

Table 3. Factor loadings for the items of the scale "setting rating".

Items (7-point Likert-scales: 1=lower end – 7=upper end)	Factor loading
What is your spontaneous evaluation of this technical procedure?	
F511 – negative … positive?	.847
F512 – not interesting … interesting?	.734
F513 – frightening … reassuring?	.733
F514 – backward-looking… innovative?	.756
F515 – bad for the global environment … good for the global environment?	.803
F516 – bad for the local environment … good for the local environment?	.790
F520 – How realistic is this procedure in your opinion? not realistic … very realistic	.660
F530 – How safe is this procedure in your opinion? very unsafe … very safe	.833
F540 – What do you think how effective is this procedure for the mitigation of climate change? not at all effective … very effective	.842
F550 – Do you think that such a procedure is necessary to mitigate climate change? not necessary … very necessary	.843
F560 – If such a procedure was proposed to be installed next to your dwelling what would your opinion be like? Would you oppose it … support it)	.820
Note: The indications at the beginning of each line refer to variable numbering	

4. Results

A descriptive analysis of some of the further questions shows that only few participants reported to feel well-informed about CCS (6.8%), a minority had heard about it (36.4%) and most participants knew nothing about CCS (56.8%). Thus, the sample reports to have only limited prior knowledge of the technology.

An overview of the ratings of all 18 settings is provided in Table 4. Possible values of the scale reach from 1 to 7 with higher numbers referring to more positive ratings. The overall mean across settings is 4.3 which corresponds to an neutral perception towards the CCS settings described on average. The range of the setting ratings varies from 3.8 (setting 13) to 4.7 (setting 11 & 12), thus from neutral to slightly positive. Those two settings rated worst, both include a coal-fired power plant as CO_2-source and saline aquifers as storage option (setting 13 and 16); the two receiving the best ratings include biomass as the CO_2-source and do not mention a pipeline (setting 11 and 12).

Table 4. Ratings of all 18 settings.

Setting				Ratings		
	CO_2-source	Transport option	Storage option	Mean	SD	N
1	Industry	Pipeline	Saline Aquifers	4.3	1.3	99
2	Industry	Pipeline	EGR	4.3	1.2	93
3	Industry	Pipeline	Depleted natural gas field	4.2	1.2	100
4	Industry	No specification	Saline Aquifers	4.1	1.3	93
5	Industry	No specification	EGR	4.4	1.2	88
6	Industry	No specification	Depleted natural gas field	4.5	1.2	95
7	Biomass power plant	Pipeline	Saline Aquifers	4.4	1.6	87
8	Biomass power plant	Pipeline	EGR	4.5	1.2	87
9	Biomass power plant	Pipeline	Depleted natural gas field	4.2	1.4	96
10	Biomass power plant	No specification	Saline Aquifers	4.3	1.3	90
11	Biomass power plant	No specification	EGR	4.7	1.2	88
12	Biomass power plant	No specification	Depleted natural gas field	4.7	1.1	92
13	Coal power plant	Pipeline	Saline Aquifers	3.8	1.4	97
14	Coal power plant	Pipeline	EGR	4.5	1.2	91
15	Coal power plant	Pipeline	Depleted natural gas field	4.0	1.3	92
16	Coal power plant	No specification	Saline Aquifers	3.9	1.4	92
17	Coal power plant	No specification	EGR	4.3	1.4	92
18	Coal power plant	No specification	Depleted natural gas field	4.3	1.3	92
	Total			4.3	1.3	1664

To analyze differences between the setting parameters an analysis of variance (ANOVA) with three factors (CO_2-source, transport, storage) was conducted. An ANOVA is a method which analyses the effect of categorized factors on a dependent measure by comparing variances between and within the categories.[6] In our case, the variable scenario rating represents our dependent variable and CO_2-source (three categories), transport (two categories) and storage (three categories) are used as three independent factors, i.e. a multifactorial ANOVA is conducted. One of the major advantages of this method in comparison to other methods for the comparison of group means (e.g. t-tests) is, that an ANOVA also combines the analysis of main effects (i.e. differences in the dependent variable between the categories within the factors) with the analysis of interaction effects (i.e. differences in the dependent variable between categories of different factors).

The model ($F(17)=3.597$; $p < .001$, $Eta^2=.036$)[7] and the main factors for CO_2 source and storage turned out to be significant (source: $F(2)=11.196$, $p<.001$, $Eta^2=.013$; storage: $F(2)=8.775$, $p<.001$, $Eta^2=.011$ – all of them at most small effects according to the classification of Cohen). Additionally, an interaction effect between transport and storage ($F(2)=4.094$, $p<.05$, $Eta^2=.005$) was detected (which means that the ratings of some of the storage option are dependant on the ratings of some of the transport options and vice versa).

Post-hoc-tests (Tukey's HSD) revealed that respective to the source of CO_2, coal (M=4.1, SD=1.4) is rated significantly worse than biomass (M=4.5, SD=1.3) or industry (M=4.3, SD=1.2). Concerning storage, saline aquifers (M=4.1, SD=1.4) are rated worse than EGR (M=4.4, SD=1.2) or depleted natural gas fields (M=4.3, SD=1.3). However, this main effect is superimposed by the significant interaction effect and an interpretation is therefore not valid.

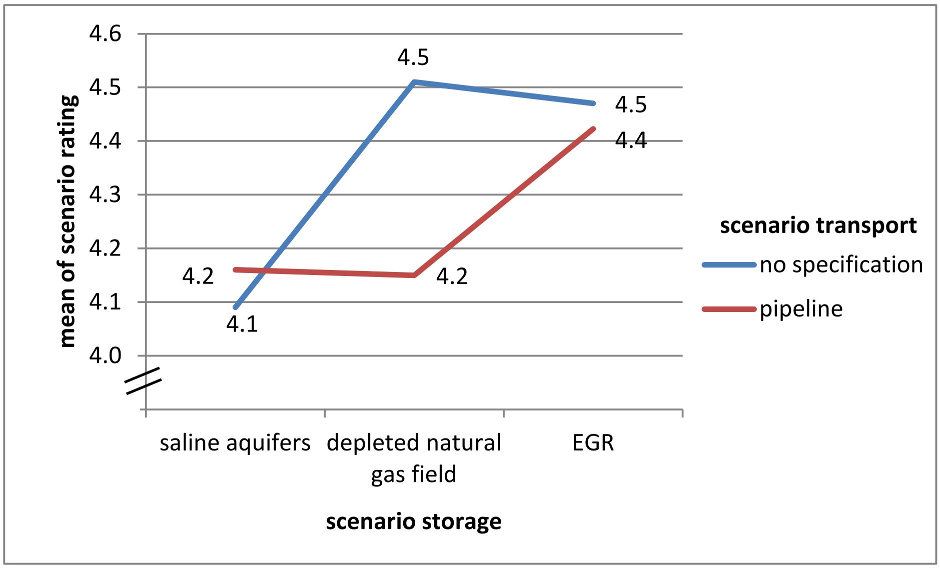

Fig.1: Depiction of the interaction transport*storage

[6] Concerning the scale of measurements, the independent variables have to represent categories, the dependent variable needs to be a metric scale, respectively the means and variances have to be interpretable (Bortz [32]). As we used a mean of 7-point-Likert-scales to measure our dependent variable, we found it suitable regarding these requirements (see Norman, p. 629 [33] or Carifio & Perla, p. 110 [34] for a discussion on these issues).

[7] The F-test is used as a test for significance, while the p-value shows the level of significance. Eta^2 is an indicator of effect size. For further information on the parameters see also Leech, Barrett, Morgan [35] p. 247 (Eta^2), p. 155 (F), p. 62 (p).

Differences between the mean values which are part of the interaction effect were tested post-hoc applying t-tests and further ANOVAs (Fig. 1). They point out that storage in saline aquifers is always rated the same independent of the fact whether a pipeline was mentioned in the description or not (t-test, t=-.53, p>.05). Similarly, EGR is rated on the same level independent of the transport option (t-test, t=.40, p>.05); however, it is rated more positively than storage in saline aquifers as pointed out by the initial ANOVA (see above, p<.001). In the case of storage in a depleted natural gas field mentioning a pipeline leads to less positive evaluations in comparison to the setting which does not mention a pipeline (t-test, t=3.30, p<.01). Thus, if no pipeline is mentioned, storage in a depleted natural gas field (M=4.5, SD=1.2) is rated on the same level with EGR (M=4.5, SD=1.3) and both more positively than saline aquifers (M=4.1, SD=1.4, ANOVA, F(2)=9.1, p<.001, post-hoc-tests: Tukey's HSD). If a pipeline is mentioned, saline aquifers (M=4.1, SD=1.5) and depleted natural gas fields (M=4.2, SD=1.3) are rated on the same level and both significantly less positively than EGR (M=4.4, SD= 1.2) (ANOVA, F(2)=3.8, p<.05, post-hoc-tests: Tukey's HSD).

5. Discussion

In this paper we present the findings from one of the first empirical studies that systematically analyze whether the specification of different parameters of CCS settings influence the public perception of the overall setting. To do so, an experimental design was developed and each participant from a representative sample of German citizens evaluated one specific setting. Our sample indicates to have only a limited knowledge about CCS – a finding that is in line with earlier and other recent research [6, 20]. We find that mean ratings for the perceptions of the settings fall into the neutral part of the answering scale. On a descriptive level this seems to suggest neither very positive nor very negative perceptions of CCS on average.

With regard to differences between the parameters specified, the results point out that settings in which the source of CO_2 is a coal-fired power plant are rated less positively than both biomass or industry settings. Thus, it seems likely that the negative perception of coal as an energy source has a negative influence on the perception of the CCS setting. Our findings are therefore in line with the results by Wallquist et al. [9] where biomass-fired power plants were preferred to gas-fired ones in CCS settings.

No such clear effects are observed in our data for the two further steps in the CCS chain transport and storage. We find that perceptions for these two factors are dependent on each other in case of storage in a depleted natural gas field. Thus, the reference to a pipeline does not have an overall negative effect in our study as could be assumed from the findings by Wallquist et al. [9], Gough et al. [24] and Schumann [20]. In the study of [9] the pipeline-factor was included in a more detailed way, i.e. also referring to the proximity of the location where the pipeline is running. It seems likely that this further variation made the pipeline such a significant factor in the participants' preferences in Wallquist's study. Why storage in a depleted natural gas field leads to less positive perceptions if a pipeline is mentioned is a question that cannot be answered based on our results.

In our sample storage in a saline aquifer was perceived more negatively than storage in combination with EGR. No earlier research has explored the perception of storage in different geological formations. Possibly this is due to the fact that saline aquifers and their attributes are on the one hand hardly known to the public and on the other hand that EGR seems to imply additional benefits. Earlier research in the CCS context has pointed out that perceived benefits are crucial for the overall acceptance of the technology [20, 22, 21].

When interpreting the results it is, however, important to keep in mind that our study only measured initial reactions to CCS settings, i.e. it is not possible to draw conclusions whether the tendencies found in our study will also be stable for long-term attitude formation or in case of the announcement of a real project. Differences in perceptions may become bigger or diminish in these cases. Furthermore, the effect sizes of the differences found between the settings are to be categorized as small. Thus, while being significant, their practical implication seems to be little.

For further research it is therefore relevant to also explore the factors that lead to the differences in the perceptions. This includes exploring whether differences may be due to individual values or different perceptions of risks. On top of this it would be worthwhile to explore whether similar relationships can be found for other energy technologies as well.

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References

[1] IEA (2010), Energy Technology Perspectives 2010, OECD/IEA, Paris.
[2] IPCC, 2014: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[3] Stigson, P., Hansson, A., Lind, M.. (2012): Obstacles for CCS deployment: an analysis of discrepancies of perceptions. Mitigation and Adaptation Strategies for Global Change 17, 601–619.
[4] Brunsting, S., de Best-Waldhober, M., Feenstra, C., & Mikunda, T. (2010). Stakeholder participation practices and onshore CCS: Lessons from the Dutch CCS Case Baren-drecht. Proceedings of the GHGT-10 Conference, Amsterdam, The Netherlands.
[5] Dütschke, E. (2010). What drives local public acceptance – comparing two cases from Germany. Proceedings of the GHGT-10 Conference, Amsterdam, The Netherlands.
[6] Pietzner, K., Schumann, D. & Esken, A. (2010). CO_2-Abscheidung und -Speicherung aus gesellschaftlicher Sicht. Ökologisches Wirtschaften, 4, 39-42.
[7] Bradbury, J. (2012). Public understanding of and engagement with CCS. In: Markusson, N., Shackley, S., Evar, B. (eds.) The social dynamics of carbon capture and storage, London, Routledge, pp- 45-73.
[8] Hammond, J. & Shackley, S. (2010). Towards a public communication and engagement strategy for carbon dioxide capture and storage projects in Scotland: Scottish Centre for Carbon Capture Working Paper 2010-08. Edinburgh: SCCS.
[9] Wallquist, L., L'Orange, S., Seigo, Visschers, V., Siegrist, M. (2012): Public acceptance of CCS system elements: A conjoint measurement. International Journal of Greenhouse Gas Control 6 (2012) 77–83.
[10] De Best-Waldhober, M., Daamen, D., Ramirez, A. R., Faaij, A., Hendriks, C., de Visser, E. (2012). Informed public opinion in the Netherlands: Evaluation of CO2 capture and storage technologies in comparison with other CO2 mitigation options International Journal of Greenhouse Gas Control 10 (2012) 169–180.
[11] Reiner et al. (2011): Opinion shaping factors towards CCS and local CCS projects: Public and stakeholder survey and focus groups. University of Cambridge. Bericht im Projekt NearCO2.
[12] Desbarats, J., Upham, P., Riesch, H., Reiner, D., Brunsting, S., de Best-Waldhober, M., Duetschke, E., Oltra, C., Sala, R., McLachlan, C., 2010. Review of the Public Participation Practices for CCS and Non-CCS Projects in Europe. Institute for European Environmental Policy, London.
[13] Special Eurobarometer 364 (2011): Public Awareness and Acceptance of CO_2 capture and storage. Report. Publication: May 2011. http://ec.europa.eu/public_opinion/index_en.htm
[14] Schumann, D., Fischer, W., Hake, J.-F. (2012) Akzeptanz der Transformation des Energiesystems in der Bevölkerung. STE Preprint, 14/2012. Forschungszentrum Jülich.
[15] Viebahn, P.; Vallentin, D.; Höller, S.; Fischedick, M. (2012): Integrated Assessment of CCS in the German Power Plant Sector with Special Emphasis on the Competition with Renewable Energy Technologies. Mitigation and Adaptation Strategies for Global Change 17(6)707–730. doi: 10.1007/s11027-011-9315-9.
[16] Mander, S., Polson, D., Roberts, T., Curtis, A. (2010): Risk from CO_2 storage in saline aquifers: a comparison of lay and expert perceptions of risk. Energy Procedia 4, 6360–6367.
[17] Upham, P., Roberts, T. (2011): Public perceptions of CCS: emergent themes in pan-European focus groups and implications for communications. International Journal of Greenhouse Gas Control, 5,1359–1367
[18] de Best-Waldhober, M., Daamen, D. (2006): Public perceptions and preferences regarding large scale implementation of six CO2 capture and storage technologies. Well-informed and well-considered opinions versus uninformed pseudo-opinions of the Dutch public. Centre for Energy and Environmental Studies. Faculty of Social Sciences, Leiden University. Amsterdam.
[19] Koornneef, J., van Breevoort, P., Hamelinck, C., Hendriks, C., Hoogwijk, M., Koop, K., Koper, M., Dixon, T., Camps, A. (2012): Global potential for biomass and carbon dioxide capture, transport and storage up to 2050. International Journal of Greenhouse Gas Control, 11, 117–132.
[20] Schumann, D. , Dütschke, E ., Pietzner, K. (forthcoming): Public perception of CO_2 offshore storage in Germany: regional differences and determinants. Energy Procedia.
[21] Kraeusel, J., Möst, D. (2014): Carbon Capture and Storage on its way to large-scale deployment: Social acceptance and willingness to pay in Germany. Energy Policy, 49, 642–651.

[22] Schumann, D., Pietzner, K., Carpantier, R. (2012). CCS-Kommunikation – Multivariate Analysen der Einflussfaktoren auf die Akzeptanz von CCS. In: K. Pietzner, D. Schumann (Hrsg.):Akzeptanzforschung zu CCS in Deutschland. Aktuelle Ergebnisse, Praxisrelevanz, Perspektiven (S. 43-66). München: Oekom.
[23] Neele, F.; Mikunda, T.; Seebregts, A.; Santen, S.; van der Burgt, A.; Nestaas, O.; et al. (2011): Towards a Transport Infrastructure for Large-scale CCS in Europe. Executive Summary No. 226317. CO_2Europipe. TNO. http://www.co2europipe.eu/. Last access: 21 März 2012.
[24] J. C., & Bernstein, I. H. (1994). Psychometric theory. New York: McGraw-Hill.
[25] May, F.; Müller, C.; Bernstone, C. (2005): How Much CO_2 can be Stored in Deep Saline Aquifers in Germany? VGB PowerTech 85(6)32–37.
[26] Grünwald, R. (2007): CO2-Abscheidung und -Lagerung bei Kraftwerken. TAB-Bericht No. 120. Berlin: TAB - Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag.
[27] Terwel, B. W. et al. (2011). Going beyond the properties of CO_2 capture and storage (CCS) technology: How trust in stakeholders affects public acceptance of CCS. International Journal of Greenhouse Gas Control, 5:2, 181-188.
[28] Ter Mors, E. et al. (2010). Effective communication about complex environmental issues: Perceived quality of information about carbon dioxide capture and storage (CCS) depends on stakeholder collaboration. Journal of Environmental Psychology, 30:4, 347-357.
[29] Daamen, D. D. L. et al. (2011). Scrutinizing the impact of CCS communication on opinion quality: focus group discussions versus Information-Choice Questionnaires: results from experimental research in six countries. Energy Procedia, 4, 6182-6187.
[30] Cureton, E. E./ D'Agostino, R. B. 1983: Factor analysis: an applied approach. Hillside, NJ: Lawrence Erlbaum Associates, S. 389 f.
[31] Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory* (3rd ed.). New York: McGraw-Hill.
[32] Bortz, J. (2005). Statistik für Human- und Sozialwissenschaftler. 7. Auflage. Springer Verlag. Heidelberg. [24][11] Gough, C., O'Keefe, L., Mander, S. (2014): Public perceptions of CO_2 transportation in pipelines. Energy Policy xxx.
[33] Norman, G. (2010). Likert scales, levels of measurement and the ''laws'' of statistics. Advances in Health Sciences Education Volume 15, Issue 5 , pp 625-632
[34]Carifio, J, Perla, R. (2007). Ten Common Misunderstandings, Misconceptions, Persistent Myths and Urban Legends about Likert Scales and Likert Response Formats and their Antidotes. Journal of Social Sciences 3 (3): 106-116, 2007
[35] Leech, N., Barrett, K., Morgan, G. (2005). SPSS for Intermediate Statistics: Use and Interpretation Psychology Press, 2005.
[36] EEPR factsheet Carbon Capture and Storage summary, 2013, http://ec.europa.eu/energy/eepr/projects/files/carbon-capture-and-storage/ccs-eepr-summary_en.pdf (Retrieved 13/06/14).

Annex

Exract from the questionnaire: Text on scenarios and items

We now present a technical procedure that is relevant in the context of climate change. Please read the description carefully as we would like to ask for your evaluation of the procedure afterwards.

CO_2-source	CO_2 and other greenhouse gases are the causes of climate change**.**
Option industry	Major amounts of CO_2 are resulting from energy-intensive processes like the production of cement or steel.
Option biomass	Power-plants fired by biomass generate energy through burning organic substances like wood waste, straw or corn. During this process only so much CO_2 emerges as the plants took from the atmosphere when they were growing.
Option coal-fired power-plant	Major amounts of CO_2 result from burning coal to generate energy.
	It is possible to reduce CO_2-emissions by preventing that the CO_2 is released into the atmosphere. This can be done by capturing the CO_2 [Option industry: during the industrial process] [Option biomass: in the biomass power-plant] [Option coal-fired power-plant: parallel to the combustion of coal] and by subsequently storing the CO_2 for a long time. This technology is called CO_2-capture and storage („Carbon capture and storage", CCS) and can also be used for other processes. If the CO_2 is stored safely, and thereby prevented from being released into the atmosphere, it cannot reinforce climate change. [Option biomass: Through this approach the amount of CO_2 in the atmosphere can be reduced.]
Transport	
Pipeline	When the CO_2 is captured, it can be transported via pipelines to places for underground storage.
Not mentioned	
Storage	
Saline aquifere	Possible places for storage of CO_2 in Germany are deep underground layers of saline water-bearing permeable rock, so-called saline aquifers.
EGR	Possible places for storage of CO_2 in Germany are natural gas fields. Injecting the CO_2 into the gas field may also contribute to extracting more gas from the field. This process is called Enhanced Gas Recovery (EGR).
Depleted natural gas field	Possible places for storage of CO_2 in Germany are depleted natural gas fields.

- 1) After having read the description, please indicate what you think about this procedure.
  What is your spontaneous evaluation of this technical procedure?
  a) (1=negative; 7=positive)
  b) (1=not interesting; 7=interesting)
  c) (1=frightening; 7=reassuring)
  d) (1=backward-looking; 7=innovative)
  e) (1=bad for the global environment; 7=good for the global environment)
  f) (1=bad for the local environment; 7=good for the local environment)
- 2) How realistic is this procedure in your opinion?
  (1=not realistic; 7=very realistic)
- 3) How safe is this procedure in your opinion?
  (1=very unsafe; 7=very safe)
- 4) What do you think how effective is this procedure for the mitigation of climate change?
  (1=not at all effective; 7=very effective)
- 5) Do you think that such a procedure is necessary to mitigate climate change?
  (1=not necessary; 7=very necessary)
- 6) If such a procedure was proposed to be installed next to your dwelling what would your opinion be like? Would you…
  (1=oppose it; 7=support it)

The questions 1-6 also included an answering option „don’t know/not specified“.